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The Editors

Disturbances in the Ionospheric $F2$ Region Associated with Geomagnetic Storms I. Equatorial Zone

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Abstract

In this paper an attempt is made to explain the ionospheric $F2$ disturbances on the equatorial zone as the effect of the vertical drift of the electron caused by the electric field deduced from the disturbance-daily variation of the earth's magnetic field. The geomagnetic and the ionospheric data are those of Huancayo on the magnetic equator. The calculations of the disturbed variations are carried out for the individual ionospheric disturbances.

The results show that the calculated variations of the disturbances using the geomagnetic data are well in accordance with the observed ionospheric data, both in the magnitudes and in the characteristics of the variations. Therefore the ionospheric $F2$ disturbances near the magnetic equator can be interpreted as the effect of the vertical drift of the electron.

1 Introduction

In the previous paper [1] the influences of the vertical drift of the electron on the ionopheric $F2$ disturbances associated with the geomagnetic storms were discussed on the data in middle latitudes. At that time the discussion was made of the average state of the disturbances. However, glancing over the many disturbances in each season, it appears that the study should be carried out for the individual states of the disturbances rather than the average state of them, because the features of the individual disturbances are fairly different from those of the average state. Based on this viewpoint, the study for the individual disturbances is made in this paper under the assumption that the $F2$ disturbances are caused by the electron drift. The geomagnetic and the ionospheric data used here are those of Huancayo. The reason why the data of this station is adopted is that since this station situates on the magnetic equator, we need not to take into account the effect of the wind, and the expression of the electrical conductivity is much simplified. (The same attempt will be made for the data in middle latitudes in the next paper.) The vertical drift of the electron is considered to be caused by the electric field deduced from the disturbance-daily variation of the geomagnetic field. The calculations of the disturbed variations are done for the period of 48 hours starting from the commencement of the geomegnetic storm, and they are compared with the corresponding ionospheric variations.

2 Deduction of Vertical Drift Velocity and Solution of Continuity Equation

It is difficult to deduce the disturbance-daily variation from the data of one storm in one station. Therefore the following method is adopted for the convenience. The value of the horizontal intensity (H) for the local time nearest to that of the commencement of the geomagnetic storm is taken and from this value the mean value of H on five international quiet days corresponding to that hour is subtracted. The value thus obtained is the disturbed part at hour zero of the storm time. The same process is followed for the succeeding 60 hours (two days and 12 hours). They are denoted as ΔH. Next, the overlapped mean of 24 hours is computed for the former 48 hours, assuming that the disturded values berore the beginning of the disturbance are zero. This variation can be said to correspond to the D_{st} variation of the average state. When this variation is subtracted from ΔH, the residue can be said approximately to correspond to the disturbance-daily variation for the geomagnetic storms.

The velocity of the vertical drift of the electron for the disturbance is approximately given by

$$v_d = \frac{\Delta X}{2\pi KF} \tag{1}$$

where ΔX is the x (north) component of the geomagnetic disturbance-daily variation ($\Delta X \simeq \Delta H$), K the electrical conductivity of the ionosphere which equals to σ_3 as shown by Hirono [2] Baker and Martyn [3] and Fejer [4], and F the total intensity of the geomagnetic field. When v_d is given, the variation of the electron density of the $F2$ region is given by

$$\frac{\partial n}{\partial t} = q(t,z) - \beta(z)n - v(t)\frac{\partial n}{\partial z} \tag{2}$$

if it is considered that the disappearance of the electron is due to the attachment and no height gradient of the vertical velocity exists. In the equation q and β represent respectively the electron production rate and the attachment rate of the electron, v the sum of v_d and v_q, the vertical velocity on the quiet day deduced from the geomagnetic S_q variation, t the time and z the height coordinate. By solving the equation (2) the variation on the disturbed day is obtained. The disturbed variation which we need is given by subtracting the daily variation on the quiet day from the variation on the disturbed day. The daily variation on the quiet day is derived by solving the continuity equation in which the vertical velocity equals to v_q deduced from the same expression as (1), where ΔX represents the north component of the geomagnetic S_q variation in the month when the storm occurs, and K equals to that on the disturbed day. Obtaining the disturbed variations, these are compared with the ionospheric data.

3 Calculations of Disturbed Variation

The electrical conductivity K ($=\sigma_3$) is studied by Hirono and others and the daily variation is given by Hirono and Maeda. [5] In the present case we use the same value as that by Hirono and Maeda both for the quiet and disturbed days. Then K

is given by

$$K=1.73\times 10^{-7}p(t)\ e.m.u. \tag{3}$$

where $p(t)$ is the daily variation factor and given by Table 1.

Table 1 Daily variation fator $p(t)$.

Local Time	0^h	2	4	6	8	10	12	14	16	18	20	22
	0.27	0.21	0.21	0.58	1.36	2.2	2.57	2.2	1.36	0.58	0.21	0.21

Since the variations and the magnitudes of the electron density and height are approximately the same in each season at Huancayo, the seasonal variation of $p(t)$ is not considered. The height distribution of β is shown in Fig. 1.* This height-distribution of β is analogous to what has been taken by Hirono and Maeda with which they have discussed successfully the quiet daily variations of the $F2$ region near the magnetic equator. We examined some other distributions of β, based on the viewpoint that the quiet $F2$ daily variations may be influenced much by the vertical drift on the quiet day, and it was found that the distribution analogous to the one used here, which means that the maximum production of the electron situates in the region where the great disapperance rate of the electron takes place, is appropriate for the present viewpoint. This is the reason why the distribution shown in Fig. 1 is adopted.

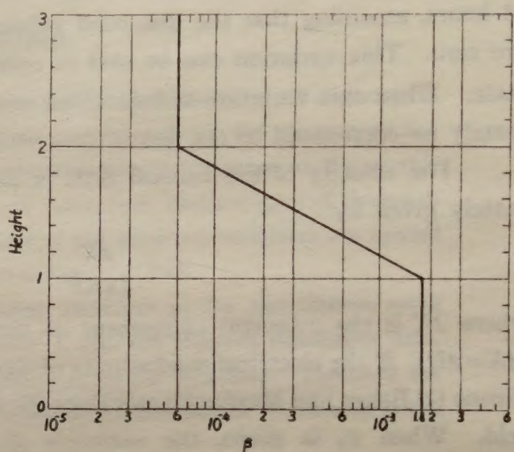


Fig. 1 Height distribution of β (in unit of sec^{-1}). Height is shown in the unit of scale height and the height 0 corresponds to the height of the maximum production of the electron.

The daily variations on the quiet day of the maximum electron density and the height are obtained by solving the continuity equation by Millington's method [6]. Then the equation is replaced by

$$\sigma_0\frac{d\nu}{d\phi}=|F|_z-|\xi|_z\nu,$$

$$\frac{dz}{d\phi}=1.37\times 10^4 v_q, \tag{4}$$

where $t=1.37\times 10^4\phi$, $1/\sigma_0=1.37\times 10^4\beta_0$, $1/n_0=\beta_0/q_0$, $\nu=n/n_0$, $\beta=\beta_0\xi_z$ (β_0 is constant) and $|F|_z=\exp[1-z-e^{-z}\sec\chi]$ if $q=q_0\exp[1-z-e^{-z}\sec\chi]$ (χ is the solar distance and q_0 is constant). The representative daily variation of the $F2$ region on the quiet day is shown in Fig. 2, using the mean value of the S_q variations during the years 1938–1939. This is compared with the observed variation shown in Fig. 3 in the corresponding years. (The variation of the height of the maximum electron density is the mean variation in 1940).

* The values of β at any heights in Fig. 1 of the paper [1] should be multiplied by a factor two.

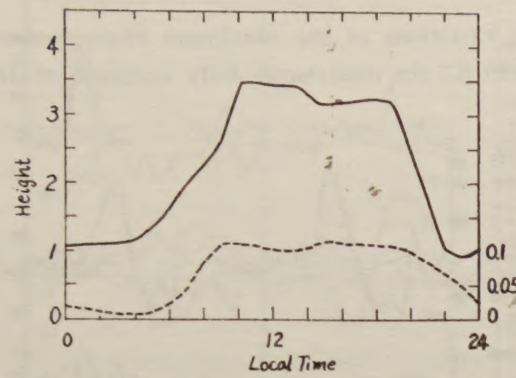


Fig. 2 Calculated daily variations of the maximum electron density (dotted line, right ordinate) and the height (full line) at Huancayo

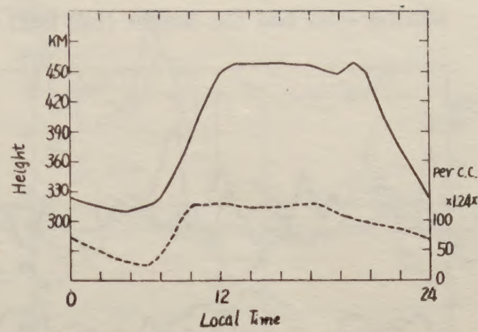


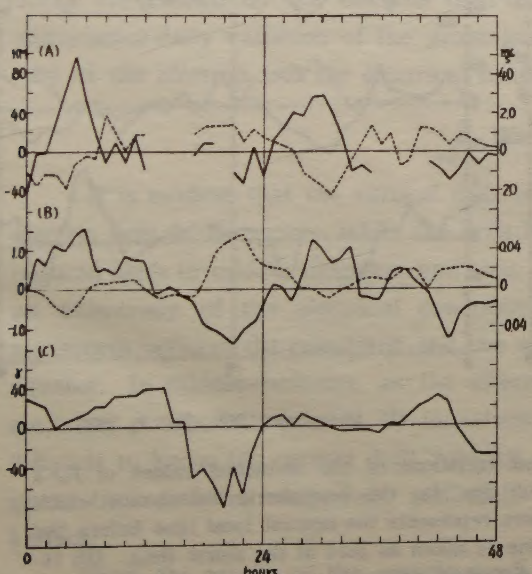
Fig. 3 Observed daily variations of the maximum electron density (dotted line, right ordinate) and the height (full line) at Huancayo

Next the variations on the disturbed day are obtained by solving the equation

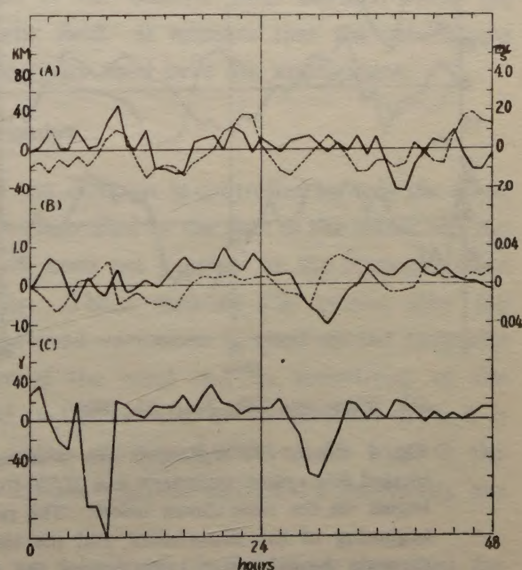
$$\sigma_0 \frac{d\nu}{d\phi} = |F|_z - |\xi|_z \nu,$$

$$\frac{dz}{d\phi} = 1.37\times 10^4 (v_q + v_d), \qquad (5)$$

From the variations of the $F2$ region on the disturbed day thus obtained for each storm the variations on the quiet day are subtracted. These disturbed variations are compared with the corresponding observed data. The calculations are made for the data of eight geomagnetic storms which occurred during the years 1938–1939. The storms are selected from those whose K indices reach 5 or 6. The results are shown in Fig. 4 (a)–(h). In these figures (A) represent the observed variations of the disturbed values of the critical frequency (dotted line) and the virtual height (full line) of the $F2$



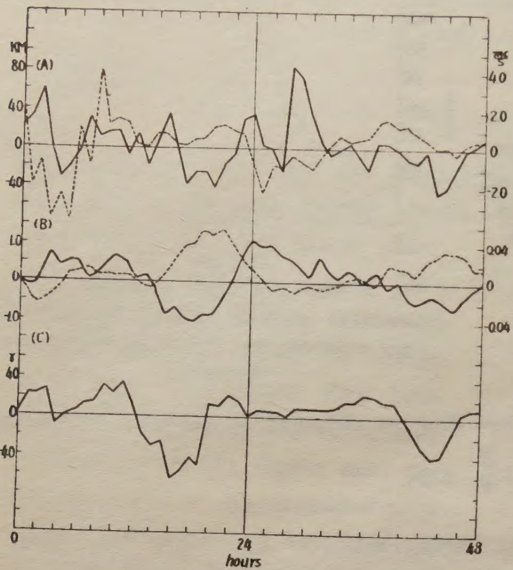
(a) Huancayo, 16h, Feb. 13, 1938



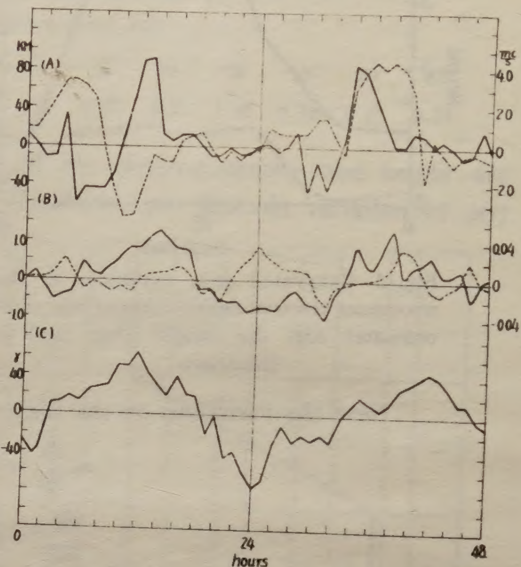
(b) Huancayo, 6h, May 24, 1938

Fig. 4 (see next page)

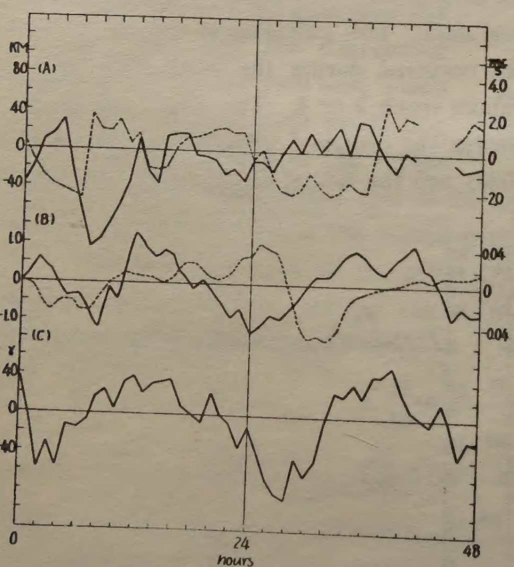
region, (B) the corresponding calculated variations of the maximum electron density (dotted line) and the height (full line) and (C) the disutrbance-daily variation of ΔH.



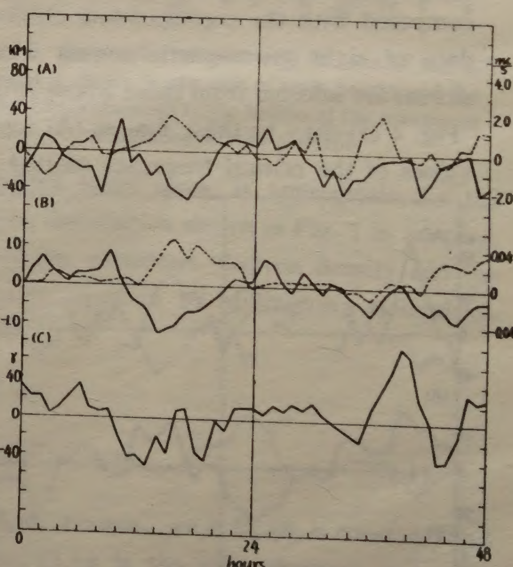
(c) Huancayo, 19h, Jan. 4, 1939



(d) Huancayo, 15h, Feb. 5, 1939

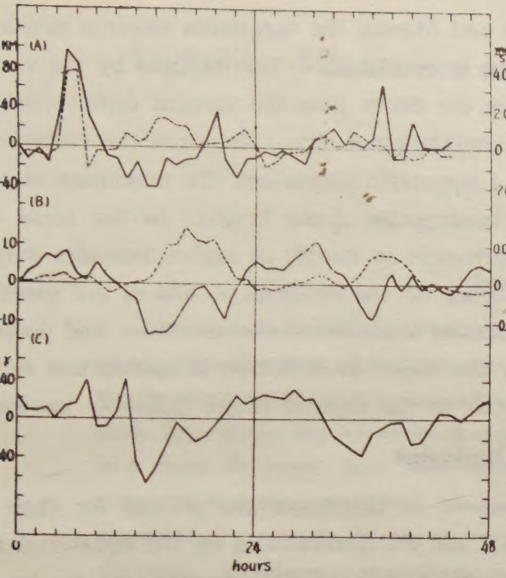


(e) Huancayo, 13h, Mar. 27, 1939

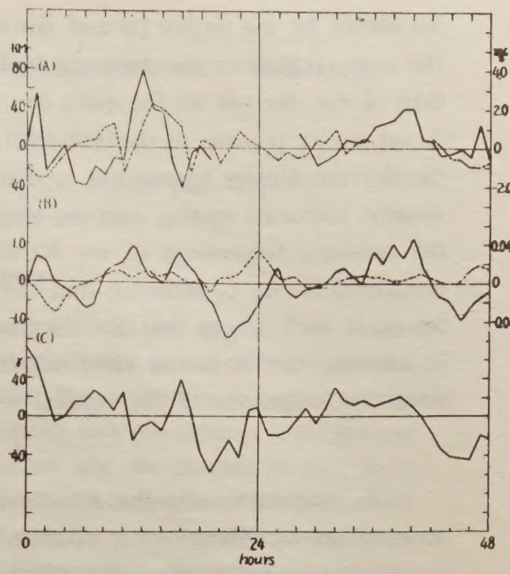


(f) Huancayo, 20h, Jul. 2, 1939

Fig. 4 (a)–(h) (A) represents the observed variations of the disturbed values of f_0F2 (dotted line, right ordinate) and $h'F2$ (full line) for the ionospheric disturbance which begins on the time shown below. The time represents the nearest local time before the beginning of the disturbance and the time is taken as zero of the storm time. (B) represents the calculated variations of the disturbed values of maximum electron density (dotted line, right ordinate) and the height (full line), using the geomagnetic variation shown in (C). (C) represents the observed disturbance-daily variation of ΔH.



(g) Huancayo, 23h, Jul. 13, 1939



(h) Huancayo, 13h, May 23, 1940

The general features of the disturbed variations at Huancayo are such that the height increases at night and decreases in the daytime, while the electron density increases during several hours centered on noon and decreases at hight. It is noted that the statistical results by Martyn [7] and Sinno [8] are different from the features of the individual cases. From Fig. 4 it is evident that the coincidence of the disturbed variations of the maximum electron density and the height for the observed and the calculated results is very good, both in the magnitudes and in the characteristics of the variations. This implies that the disturbances of the $F2$ region at Huancayo (and on the equatorial zone) are caused by the electron drift due to the electric field deduced from the disturbence-daily variation of the geomagnetic field. It appears that the attachment rate of the electron and the electrical conductivity used here are appropriate.

4 Discussion

It is evident that the vertical drift of the electron is controlled by only the static electric field at Huancayo, while the drift is controlled by the sum of the static and the induced fields in middle latitudes, and that we need not consider at the former station an anisotropy of the electrical conductivity. These may be the reason why the agreement between the calculated and the observed variations is good on the magnetic equator. In middle latitudes, as the effects of the wind and an anisotropy of the electrical conductivity are to be introduced in the velocity of the electron drift, it is diffucult to know the correct drift velocity, unless the actual state of the wind in the storm time and the magnitude and daily variation of the electrical conductivity are known.

From the results of the present work we may have the following viewpoint for the cause of the variation of the electron density of the $F2$ region in the storm time.

As shown by the author [9] and Hirono and Maeda, the maximum electron density of the static region on the magnetic equator is decreased, in the daytime by the vertical drift of the electron on the quiet day. In the storm time the vertical drift velocity v_d is set up in reverse to the velocity v_q on the quiet day. Therefore the variation of the electron density approaches to that of the static region and the maximum electron density increases in the daytime with the decrease of the height. In the same way the seasonal behaviours of the $F2$ disturbances in middle or higher latitudes may be accounted for by considering that the phases of the veocities v_d and v_q are generally set up in such a way that the electron density tends to increase in winter and decrease in summer, but it is not clear whether the above presumption is appropriate or not, since the magnitude of the vertical velocity of the dectron is not definitely known.

5 Conclusion

In this work, only the $F2$ disturbances at Huancayo are studied for their individual states. Hewever, it appears that the $F2$ disturbances on the equatorial zone can be interpreted as the effect of the vertical drift of the electron set up by the electric field deduced from the geomagnetic disturbance-daily variation. Thus the suggestion by Martyn [7] appears to be established at least near the equator. The results in this papes may suggest that the drift theory may play an important role in the interpretation of the $F2$ disturbances also in higher latitudes. We are now studying the $F2$ disturbances in middle latitudes in the same way as that in the present case (using the data of Watheroo and Kakioka) and the results will be published in near future.

Acknowledgements

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Lightning Mechanism and Atmospherics Radiation

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Synopsis

Simultaneous recording of electro-static field change, waveform of atmospheric, lightning flash photograph, were obtained with partial success during the the thunderstorm observation in summer 1955. The simultaneous records of electro-static field change, and waveform of atmospheric, each pair obtained at the moment of a cloud discharge, have been investigated and the possibilities have been suggested that some of the slow discharge processes in thundercloud will be mainly composed of corona discharges of various types between two charge centres in the cloud. Waveform of atmospheric, and lightning flash photograph, both relating to the same cloud discharge, have made it clear that the very rapid dart leader radiates the atmospheric with waveform of main discharge type. The directly correlated records of electro-static field change, and waveform of atmospheric, were also obtained concerning several ground discharges. This has made it possible to classify the recorded ground discharges into two types according as the discharge has α type stepped leader, or β type, following to the principle orginally reported by Schonland (1). The investigation indicates that no less than 60% of the recorded ground discharges has β type stepped leaders in this thunderstorm season. In spite of the insufficient number of available data at present it seems reasonable to consider that the greater part of the ground discharges in our country have β type stepped leaders.

It has also been made clear that the streamer emitting an outstanding single pulse, such as the return streamer of ground discharge, is always associated with secondary and somewhat slow discharge processes.

I Introduction

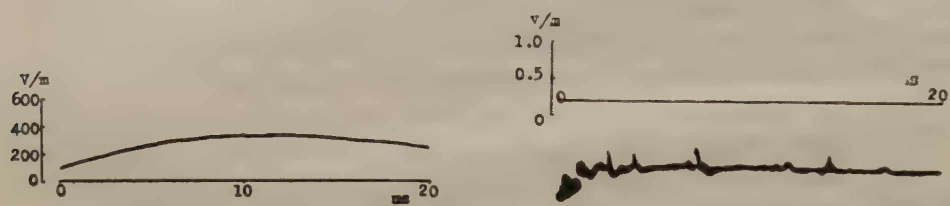
There are great many varieties among lightning dicharges and they change their appearances not only from a thunderstorm to another but also from discharges occurring at a certain stage of thunderstorm to those at another stage of the same storm. Corresopondingly the waveforms of atmospherics radiating from these lightning discharges are very diverse and in addition much complicated. The discharges occurring at slow rates in thunderclouds are esspecially complex. It remains here many points unknown concerning the mechanisms of cloud discharges, because the luminous phenomena associated with discharges in thundercloud can very hardly be photographed. To investigate these points more clearly, another new amplifier channel of super-heterodyne type with the tuning frequency 10 Mc/sec. has been attached to the previous waveform recorder [2]. This channel simultaneously triggers two recording C.R.T.'s

which give the wasveform of atmospheric and the static field change on respective fluorescent screens. The image reproduced on these two C.R.T. screens are photographed in respective frames on 35 mm film by respective cameras. This improvement of the apparatus has made is possible to record the variation of electro-magnetic field due to lightning discharge to ground from leader to return, which was very difficult with the previous one. Accordingly it has also become possible to compare the waveform, and the static field change, of a lightning discharge with the resolved photograph of the same lightning flash and to analyse the correlation between discharge mechanism and radiation of atmospheric.

II Investigation of the observational facts

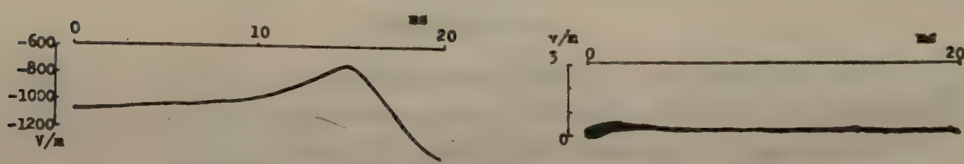
1. Cloud discharges producing slow electro-static field changes.

Two examples of typical records, each obtained at the moment of a cloud discharge, are illustrated in Fig. 1. and 2. In these figures, A represents the electro-static field change, and B the corresponding wave-form of atmospheric, each pair produced by the same cloud discharge. These two illustrate the case where the cloud discharge produces the slow static field change, which shall be denoted as "S-process" in what follows. It is now generally recognized among research workers in the



A B

Fig. 1. Cloud discharge producing slow electro-static field change and grouped radiatian pulses.
A. Slow electro-static field change.
B. Waveform of atmospheric with grouped pulses.



A B

Fig. 2. Cloud discharage producing slow electro-static field change and isolated radiation pulses.
A. Slow electro-static field change.
B. Waveform of atmospheric with isolated pulses.

world that the greater part of cloud discharges are composed of these S-processes. Simultaneous and continuous method of recording the waveform of atmospheric, and the static field change, performed in our country concerning cloud discharges [3], revealed the fact that radiation pulses present themselves at mean time intervals 8–16 m-sec. in the course of a S-process, taking the form of groups with mean

duration of several m-sec. in one case, and the form of isolated pulses in another. In contrast to this continuous method of recording, the present apparatus picks up the phenomena in the period of 20 m-sec. after the recording has been triggered by a pulse of atmospheric, and hence it catches the moment of a cloud discharge when a certain group of pulses is coming about. Fig. 1 shows the case where S-process emits groups of pulses intermittently, and Fig. 2. the case where the process emits isolated pulses at time intervals roughly no less than 20 m-sec. Table 1. represents the number of recorded waveforms of grouped pulse type, and the isolated pulse type, both radiating from cloud discharges, and indicates that the occurrence probabilities of these two are nearly the same. To investigate the differences of time rates of slow static field changes between these two types, the mean time rate has been measured for each case employing 18 records of static field changes, produced by the processes occurring at distances in the range 8–10 km. from the station, and included both these two types.

Table 1. Number of recroded waveforms of grouped pulse type, and isolated pulse type, referring to cloud discharges.

	Grouped pulse type	Isolated pulse type
Number of recorded waveforms	71	70

The result is shown in Table 2., which seems to indicate that although by cloud discharges emitting grouped pulses can the electricity be transferred a little faster than by those emitting pulses scatteredly, it is unlikely to consider any significant differences lying between these two. This can be interpreted by the fact that the amplitude of a radiation pulse is not determined by the quantity of electricity transferred by the rapid streamer process related to it along a discharge channel, but mainly determined by the

Table 2. Time rates of electro-static field changes produced by S-processes.

Distance	Grouped pulse type	Isolated pulse type
8-10 km.	9.4 v/m. m-sec.	7.5 v/m. m-sec.

time rate of electric current variation along it, and the discharge streamers emitting radiation pulses do not seriously contribute to transfer the electricity. However these streamer discharges may contribute, though only a little, to the transfer of electricity, if they come into existence intermittently forming large groups of pulses in the course of a cloud discharge. This seems to interpret the slight difference of the time rates of slow field changes between grouped pulse type, and isolated pulse type, as indicated in Table 2. The greater part of electricity contributing to a cloud discharge therefore must be transferred, and canceled out, by other discharge mechanisms with slow and continuous character. These mechanisms of cloud discharges are of course very different from those of rapid streamer discharges emitting radiation pulses. As individual radiation pulses appearing in each group on the waveform of S-process present themselves

neraly at random [4], it seems reasonable to censider that during the course of S-process, random but rapid streamers on small scales present themselves in grouped form in one case and in isolated form in another. S-process may be considered to have the very similar nature to that of J-process occurring in the intervals between strokes of multiple ground discharges [5], F-process often occurring at the final stage of less multiple ground discharges [6], and the continuting stroke following upward stepped leaders [7]. However only a little has been known about the mechanisms of S-processes up to the present. If S-process taking place in thundercloud has the same machanism as J-process has, it must be composed of the positive streamer that results in the transfer of positive electricity in the cloud. Allibone and Meek [8] made experimental studies on the development of long spark discharge and showed that the velocities of leader streamers increase with discharge gap-length independent of their polarities, if all other conditions are the same. An example of their results is shown in Table 3. If the relation holds good from

Table 3. Variation of leader velocities with gap-lengths in experimental spark discharges.

Polarity	Discharge gap-length (mm.)	Velocity of leader streamer (cm/sce)	Over voltage (%)
−	25	6×10^6	0
−	150	17×10^6	0
+	25	4×10^6	0
+	150	15×10^6	0

experimental spark discharges on small scales to lightning discharges on huge scales, the negative pilot streamer appearing in the first leader of ground discharge must have larger velocity than what is represented in Table 3., as the extreme case of long spark discharges. The observed velocity values of pilot streamers in discharges to ground are reported to be in the range $1-8\times10^7$ cm/sec. [9], which seems to support this point. Being considered from the theoretical point of view, the positive leader streamers, as Allibone and Meek indicates [8], must have velocitis larger than those of negative one, which is really supported by the results of experimental studies on spark discharge development [8]. An example of them is illustreated in Table 4. If the arguments can be applied to lightning leader streamers developing in unionized atmosphere, the velocities of positive leader streamers must be larger than those of negative ones. Therefore the velocities of the formers developing in the virgin atmosphere can be estimated to be in the range $3\text{-}16\times10^7$ cm/sec. under the assumption that the relation

Table 4. Variation of leader velocities with gap lengths in experimental spark discharges.

Polarity	Discharge gap-length (mm.)	Velocity of leader streames (cm/sec)	Over voltage (%)
+	71	2.6×10^6	0
−	71	1.5×10^6	0

indicated in Table 4. is applicable to the case of lightning discharges. The actual velocity of J-process streamer was originally estimated by Malan and Schonland [5]

to be about 3×10^6 cm/sec. from the investigation of slow electro-static field changes occurring in the intervals between strokes of gound discharges, under the assumption that the positive streamer develops upward in the negatively charged column in thundercloud during periods of stroke intervals, and later this was more directly determined by Hewitt [10] from time interval measurements of radar echoes from the channel of ground discharge. Hewitt sometimes observed that the time interval between the direct pulse, and the echo pulse that was assumed to come from J-streamer channel, increased slightly with time in steps from one stroke to the next, and estimated the vertical velocities of the assumed J-streamer at $0.4\text{–}1\times10^6$ cm/sec. F-process, as reported by Malan [6], may also be considered to be a kind of J-process that often occurs after the last stroke of a multiple discharge to ground with roughly less than 4 strokes, and the velocity of it was estimated by him at about 2.5×10^6 cm/sec. This seems not to agree with the results deduced from experimental studies on long spark discharge development. The reason for this may be the following two: first, in the atmosphere, such as the interior of thundercloud, does the positive streamer develop slower than it does in the experimental spark gap; and second, the slow and continuous discharge in thundercloud involves not only discontinuous rapid streamer discharges, but also continuous slow corona discharges at the same time, and indeed, it often happens that the former occupies only a small part of a cloud discharge and the latter occupies the greater part of it. Both of these two may be considered to occur often simultaneously in thunderclouds, but which of these occurs more frequenly and is more probable than the other, it is a matter of question at present.

The discharges in thunderclouds can very often be reduced to the model that is composed of a discharge between two change centres [11] with spherical forms, one of which is positive and lies in the upper part of a thundercloud, and the other is negative and lies in the lower part of it. The radius of spherical regions constructing these two charge centres, and carrying the electricity contributing to a lightning discharge is estimated to be about 0.1 km. [12]. When the potential gradient round these two assumed charge centres, the separation of which is estimate at about 5 km., reaches to the critical value necessary for the onset of corona discharges, the corona will come about along the surface of inward hemispheres of the two opposing charge centres. The dark current region that connects these two corona regions, and carries the discharge current, will have a columnar form, the radius of which will of course vary from one position to another between these two charge centres. As the corona current density through the electrode surface, computed from the experimental corana discharge between two parallel wires [13], is about 1.3×10^{-7} amp/cm^2, the corona current of the cloud discharge will be estimated at about 80 amp., under the assumption that the current with this density flows out through hemispherical surfaces of the two charge centres. This is in good agreement with the average value of the order 10^2 amp. of current of S-processe in thundercloud, which has been computed under the assumption that one S-process in the cloud discharges 20 coul. in 0.2 sec. on the average; this seems plausible enough, if we consider the observational facts about discharges in

the cloud. Following to the above discussions, it is possible to infer the coronas as well as slow positive streamers existing in thunderclouds. The corona type discharges in the cloud necessarily has the continuous character and can more readily develop from positive charge centre than negative one, because this type is mainly composed of corona processes between two equally opposing charge centres that lie in the upper positive region of the cloud and the lower negative region of it respectively. The non-uniform distribution of electricity within each centre, and the irregularities in electric field around it, probably, accelerate the production of intermittent streamers on small scales, such as brush corona, and streamer corona, which can be observed in experimental corona discharges. This seems to explain the observational fact that the random radiation pulses assumedly related to streamer discharges occur in the coures of a slow continuous discharge in the cloud. Because in the actual cell of a thundercloud the electro-static field scarcely exceeds 3×10^3 v/cm [14], and any appreciable positive space charge triggering a cloud discharge can hardly be considered to exist in the interior of the cloud, in contrast to the case of discharge to ground; the greater part of cloud discharges must be initiated by these corona processes. The positive corona generally develops more readily than negative one, as experiments indicate, hence the random corona streamers that occasionaly occur in the course of a slow cloud discharge, depending on conditions round two charge centres, must mainly have positive polarity. The velocities of positive streamers estimated from the results of experimental spark discharges are roughly 10^8 cm/sec. [15], and the same order of magnitude as those of dart leaders, therefore the widths of radiation pulses appearing in the course of a cloud discharge seems to be interpreted by positive corona streamers, as well as negative dart leaders [16].

2. Cloud discharges accompanying step field changes.

Some of the cloud discharges produce rapid changes of electro-static field, which will be denoted as "R-process" in the followings, and an example of which is illustrated in Fig. 3. In the figure, A shows a step field change, and B a clear single radiation pulse, both produced by the same R-process. This seems to suggest that the cloud discharge process producing a fairly outstanding step field change is mainly composed of rapid streamer emitting a clear radiation pulse. This kind of rapid streamer can, in some cases, be considered as being the special dart leader, because the leader is the only kind of rapid streamer process that has been observed in non-ground discharges. This will be illustrated just further on. In Fig. 3., A indicates that the step field change is produced by R-process in 3 m-sec., and B the corresponding radiation pulse being emitted in only 1.6 m-sec. It can be concluded from these facts that even the special dart leader streamer, occurring in the course of a cloud discharge, and emitting single radiation pulse, always accompanies secondary discharges with somewhat slow time rates. This will also be discussed later on again. Fig. 4. illustrates the case where the rapid dart leader emits the outstanding radiation pulse of main discharge type. A shows the cloud flash, photographed by Boys' camera, and composed of single dart leader, and B the radiation pulse emitted by this cloud dis-

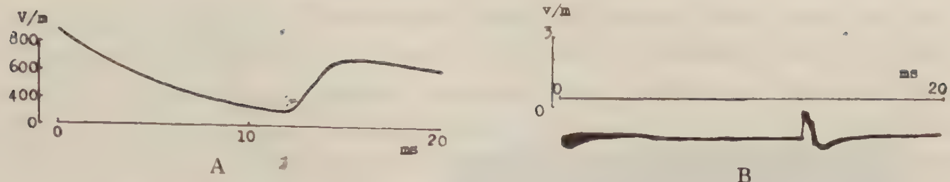
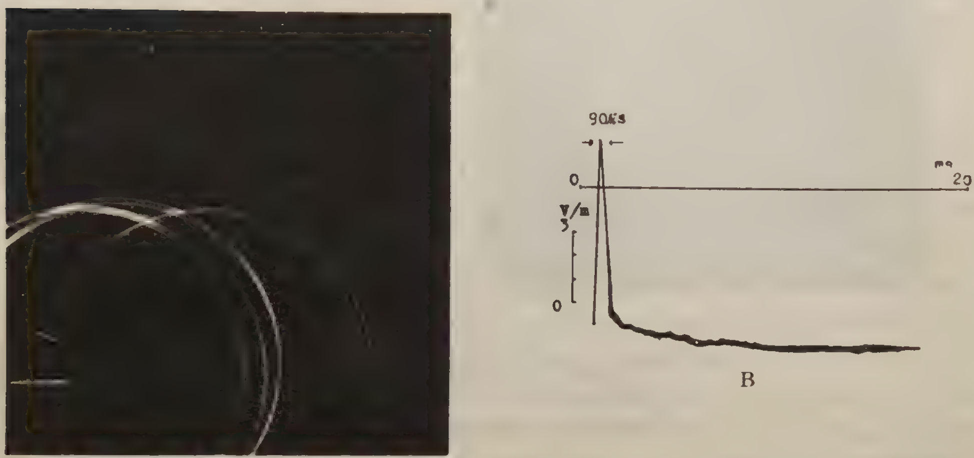


Fig. 3. Cloud discharge accompanying step field change.
A. Step electro-static field change.
B. Radiation pulse corresponding to A.

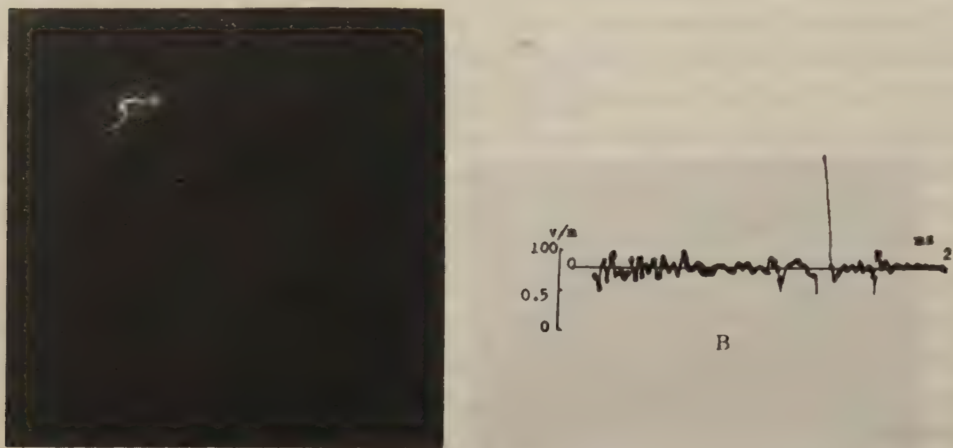


A

Fig. 4. Cloud discharge emitting main discharge type waveform.
A. Cloud flash photographed by Boys' camera.
B. Main discharge type waveform corresponding to A.

charge. As the waveform illustrated in Fig. 4. B has the very similar structure to that of main discharge type, it may be reasonable to consider that this waveform is emitted by the dart leader illustrated in A. It is evident, on the other hand, from the visual observation that this cloud discharge was photographed at the distance about 10 km. from the discharging point, therefore the total channel length of the flash can be estimated at about 4 km. by measuring the length of image of the flash on photographic plate. The width of the corresponding pulse of the waveform can also be estimated at about 100 micro-sec. on the record B, so that the advancing velocity of this dart leader is roughly 4×10^9 cm/sec. This is much larger than $0.1–2.3\times10^9$ cm/sec., the velocity values of the dart leaders obtained by Schonland and Malan [17]. Therefore it is evident that such rapid dart leader, as the photograph illustrates, produces an outstanding field change and emits a clear radiation pulse of the similar nature to that of the main discharge type waveform. This agrees with our conclusions already deduced from the investigation of the occurrence frequency of waveforms of this type [16]. In Fig. 5., A illustrates the photograph of a cloud flash composed of six dart leaders, and B the waveform of atmospheric which was recorded simultaneously with the photograph A. As the figure indicates, the waveform is composed of random pulses forming a group with duration larger than 2 m-sec. at least. It has

no such outstanding radiation pulse that can be interpreted as being emitted by one of these six dart leaders, and is similar to the return streamer pulse illustrated in Fig. 6. Following to the discussions in Section 1., it will be probable to conclude that the



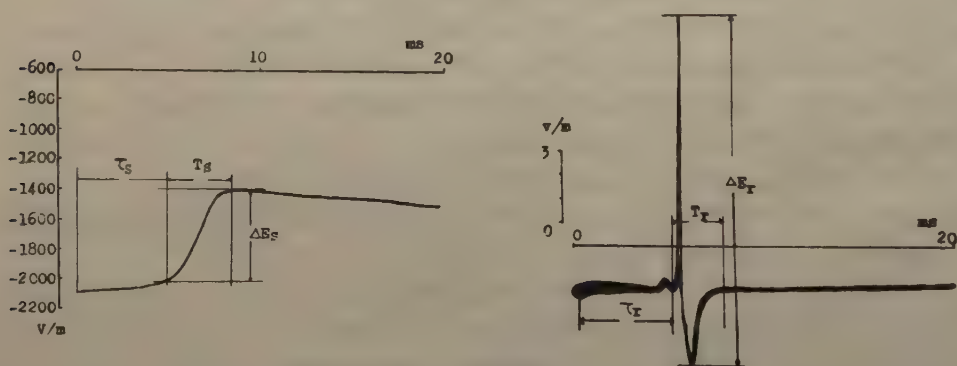
A

Fig. 5. Multiple cloud discharge emitting grouped radiation pulses.
A. Photograph of multiple cloud flash obtained by Boys' camera (six-fold discharge)
B. Waveform of grouped radiation pulses corresponding to A.

waveform of grouped pulses in Fig. 5. B is produced by small but rapid streamers, occurring at random in the course of slow discharge processes, and preceding these six dart leaders.

3. Discharge to ground.

Fig. 6. illustrates an example of the records of discharge to ground, and A shows the rapid step field change and B the outstanding single radiation pulse, both being produced by the same return stroke of discharge to ground in the vicinity. The wave-



A B

Fig. 6. Record of ground discharge.
A. Rapid step field change.
B. Waveform of atmospheric corresponding to A.

form B was obtained by using the waveform recorder with the frequency response chara-

cteristics, for which the low frequency side was cut off at 0.5 kc/sec. in order to not to record the static field component of electro-magnetic field variation, but to emphasis the radiation component of it, hence such waveforms as the figure illustrates, must fairly be distorted by these instrumental causes, and does not, of course, represent the radiation component strictly. The measurement of pulse width, Tr, of the waveform B gives the value of about 3.2 m-sec., which is much larger than the duration of luminosity, i.e., several hundred microseconds at the largest at the channel root of the ground discharge photographed by the authors [16]; so it is evident that the pulse width of the waveform of ground discharge caught by the present apparatus is generally larger than the duration of luminosity at the channel root of the relating flash, which gives the direct indication of the duration of return stroke and hence determines the true radiation pulse width on the wavform [16]. The rapid step field change of this discharge is performed in 4.3 m-sec., as the figure illustrates, so it is recognized here again that the width of radiation pulse relating to return stroke is larger than the duration of the corresponding step field change, which is the same relation as the rapid cloud discharge discussed in Section 2 has indicated already. To clear out these points further-more the starting time, τ_s, τ_r, of step field change and relating radiation pulse, were measured with regard to ground discharges, and the results are summarized in Table 5. It is clear from the table that the step field change produced by return stroke starts in every case a little earlier than radiation pulse emitted by the same stroke. This indicates that the step field change that roughly relates to a return stroke includes not only the part produced by return streamer itself but also, even a little, the part produced by the final part of the concerning leader stroke [1].

Table 5. The comparison of starting time of step field change, with that of radiation pulse, both referring to the same ground discharge.

Sign of τ_s-τ_r	+	0	−
Frequency of occurrence in %	0	55	45

The duration, T_s, of the step field change produced by return stroke, and the width, T_r, of the radiation pulse corresponding to it are measured on each pair of records of ground discharges. The percentages of the number of records that have the same sign of the value, T_s-T_r, are tabulated in Table 6., which shows that there is no cases where T_r is clearly larger than T_s.

Table 6. The comparison of duration of step field change with width of outstanding radiation pulse, both produced by the same ground discharge.

Sign of T_s-T_r	+	0	−
Frequency of occurrence in %	61	39	0

Therefore in spite of the facts that the waveforms are fairly distorted and the static field changes were recorded not sufficiently clearly, it is reasonable to conclude that the return streamer producing clear single radiation pulse does not responsible for the

whole of a step field change, but the latter is always accompanied by sowewhat slow secondary discharges correlated to the return stroke, such as the final part of concerning first leader, and the "c" portion of ground discharge or the beginning part of the following J-process. Most of the records of radiation pulses related to return strokes have the leader parts, and some of them carry many radiation pulses on their leader sections at intervals similar to those between step streamers of the first leader of ground discharge, and the others do not carry any such pulses on it. As the waveform of ground discharge recorded by the present apparatus refer to the first stroke of a ground discharge, the above difference about leader sections of the recorded waveforms must be attributed to the nature of the first leaders, i.e., the pulsive leader waveform must relate to α type stepped leader and the non-pulsive one to β type [1]. In all, 17 records of ground discharge waveforms are available for the discussion, which were caught from leader section to return stroke by the recorder adjusted to the same sensitivity. These records have been classified into three cases: α type, β type, and unclassifiable. The results are given in Table 7. The table seems to indicates that the greater part of the ground discharges occurred in this period of thunderstorm observation accompanied β type first leaders [18]. The statistical investigations previously

Table 7. The classification of the first leaders of discharges to ground.

Type of first leaders	α type	β type	unclassifiable
No. of recorded waveforms	2	10	5

made by the authors about cloud discharge waveforms recorded through past 3 summers [4], made it clear that many of the discharges in the cloud, if they involve something like stepped leaders, mostly accompany β type leaders. Hence, generally speaking, it is plausible to conclude that the greater part of stepped leaders occurring in our country are of β type, indifferent to the fact that they relate to ground discharges or to cloud discharges.

III Conclusion

It can be concluded from the above discussions that:

(1) Most of the cloud discharges are composed of slow and continuous discharge processes. It seems possible, in some cases, to interpret these processes by the discharge model, the main part of which is composed of coronas between two spherical charge centres, one of which is in the upper positive part of thundercloud and the other in the lower negative part of it.

(2) In the course of a slow cloud discharge the radiation pulses are emitted by random rapid streamers. These radiation pulses are produced in groups and form many intermittent bursts in some cases, and they form no more than the isolated random pulses in others.

(3) Some of cloud discharges produce special dart leaders with very high velocities, and the radiation pulses of main discharge type are emitted by them in such cases.

(4) In general, the rapid and large streamer emitting an outstanding radiation pulse, always accompanies secondary slow discharge processes related to the streamer.

(5) So long as our observation concerns, it is reasonable to consider that most of the stepped leaders occurring in our country are classified to β type, indifferent to the fact that they relate to cloud discharges or to ground discharges.

In conclusion authors' sincere thanks are due to Prof. A. Kimpara, the Director of our Institute, who has encouraged them throughout the present investigation. The data employed to the present investigations were obtained by using the apparatus that had been constructed by him under the aid of a Grant in Aid of the Miscellaneous Scientific Research from the Ministry of Education.

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A Palaeomagnetic Consideration on the Remanent Magnetism of the Basalt Lavas at Kawajiri-misaki, Japan

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Abstract

On the outcrop of the basalt lavas at Kawajiri-misaki (Cape Kawajiri), the present author has carried out a fairly continuous sampling of a number of test specimens from an area of one meter square of the outcrop belonging to entirely one rock block and has confirmed that the normal and the reverse natural remanent magnetism (N.R.M.) are found intermixed side by side in the very outcrop. On the other hand, the results of the thermo-magnetic analyses of the lava specimens suggest that the magnetic mineral responsible to the normal N.R.M. is predominantly a titanomagnetite of a phase having intermediate Curie point, whereas those to the reverse N.R.M. poly-phase having lower and higher Curie points than the intermediate. N. Kawai has recently proposed the idea that the self-reversal of remanent magnetism of rocks is possible to occur when the reverse magnetism of poly-phased titanomagnetites overcomes the normal of the pre-existing, single-phased, parent one of which the exsolution has produced the poly-phased ones. Both the field evidence showing the positional close intermixing of the normal and the reverse magnetizations in the same lavas and the results of the author's laboratory experiments to prove the exsolution do not seem to favour the geomagnetic field reversal hypothesis.

1 Introduction

In the previous paper [1] were reported that the basalt lavas at Kawajiri-misaki have in general reverse N.R.M., while in the belt B (Fig. 1) normal and reverse N.R.M. are found intermixed in positions, and also that for palaeomagnetic consideration a key may be afforded by a close field observation confirming whether the normally magnetized rocks are dykes penetrating the body of the reversely magnetized lavas or not, while on the other hand another interpretation seems to be given by the self-reversal idea of remanent magnetism on the assumption that both

Fig. 1 A map of Kawajiri-misaki.

the normally and the reversely magnetized rocks belong to the same lava block.

In this paper, it is reported that the present author has clarified by a close field observation that the normally magnetized rocks are not dykes and the fact of the positional intermixing of the normal and the reverse magnetizations in the same lava blocks can be explained by the self-reversal idea of remanent magnetism.

2 Field observation

Since the previous study, it has been a question whether the normal and the reverse magnetizations are intermixed in the really same rock block or not. Therefore, for the purpose of clarifying this, the author has intended to perform a close field observation and has carried out further close sampling of numerous specimens about 180 in number from an outcrop extending over a distance of about 50 meters in the

Fig. 2 A photograph of the sampling place in Kawajiri-misaki lavas.

northern part indicated by an arrow in Fig. 1 of the belt B. Finally, at a place of this outcrop he has succeeded in getting a fairly continuous sampling of a number of test specimens from an area of one meter square and has confirmed the fact that the normal and the reverse N.R.M. are found with their positions as intermixed side by side within such a small area.

Fig. 2 is a photograph of this sampling place. It is situated 7 meters high above the sea level in the middle of a rock-cliff of the Kawajiri-misaki lavas and sandwiched between two adjacent, vertical joints separated by a distance of 1.4 meter as can easily be seen in the photograph. This clearly indicates that the specimens from this place belong to the same and one rock block. The arrangement of the specimens *in situ* which he has sampled is represented in Fig. 3 which shows a side view of the fairly vertical surface of the area sampled. The directions and intensities of the N.R.N. of these specimens 26 in number have been measured by means of an astatic magnetometer. The results are shown in Fig. 4 and Table I. Fig. 4 is the Wulff's projections of the directions of the N.R.M. thus measured and in Table I are shown the intensities of the N.R.M.

As can be seen from Fig. 4, two specimens of No. 3 and No. 16 show normal magnetization, while the remaining 24 specimens are all

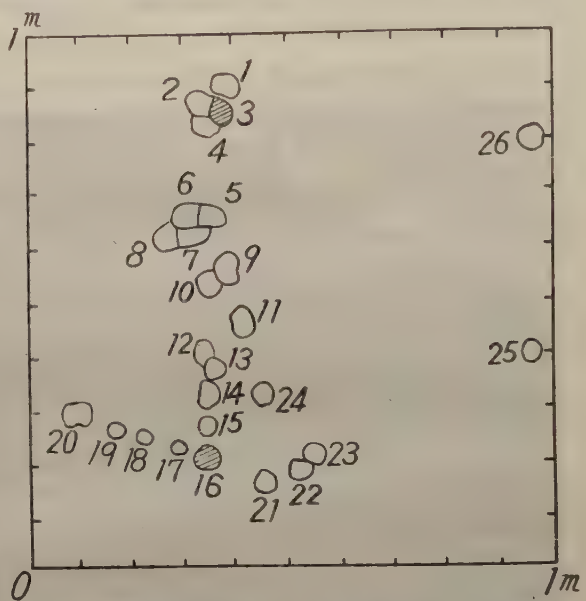

Fig. 3 The arrangement of 26 specimens sampled.
Two specimens of No. 3 and No. 16 : normal magnetization
The remaining 24 specimens : reverse magnetization

Table I Intensities of the N.R.M. of 26 specimens in the unit of 10^{-4} c.g.s.e.m.u./g.

Specimen No.	Direction	Intensity	Specimen No.	Direction	Intensity	Specimen No.	Direction	Intensity	Specimen No.	Direction	Intensity
1	R	5.2	8	R	4.0	15	R	6.7	22	R	9.3
2	R	2.3	9	R	6.7	16	N	4.0	23	R	9.0
3	N	1.2	10	R	5.7	17	R	7.8	24	R	8.1
4	R	5.1	11	R	5.6	18	R	8.2	25	R	4.7
5	R	4.2	12	R	6.1	19	R	9.5	26	R	4.0
6	R	5.3	13	R	6.5	20	R	5.1			
7	R	5.1	14	R	7.2	21	R	8.8			

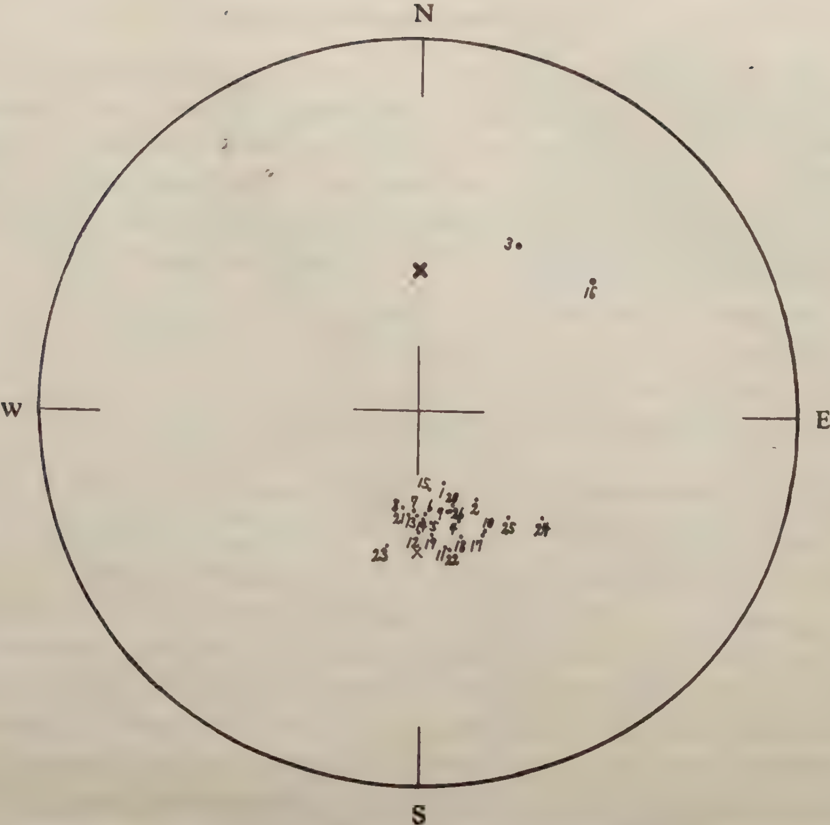

Fig. 4 Directions of the N.R.M. of 26 specimens.
Big plots represent the lower hemisphere and thin the upper. The thick cross (×) indicates the direction of the present geomagnetic field at Kawajiri-misaki whose dip is +49° downward.

reverse and there is no magnetizations having intermediate directions. It is also worth noticing that the intensities of magnetization of these 26 specimens are in the order of magnitude of 10^{-4} c.g.s.e.m.u./g. being far less than 10^{-2} c.g.s.e.m.u./g. of the normally magnetized specimens in the partial belt b. [1]

Thus, as for the basalt lavas at Kawajiri-misaki it has been confirmed that the normal and the reverse magnetizations are intermixed in positions in entirely one rock block. Moreover, the author already reported [2] that microscopic observations can hardly recognize any petrological differences between the normal and the reverse specimens of the lavas.

From these facts, it may be naturally considered that the normally and the reversely magnetized rocks would have been formed in the really same lavas of simultaneous eruption. And it is quite unlikely that two lavas of different eruption times were extruded by being intermixed side by side with the structure of mosaic pattern in such a narrow space as the above field observation shows and that the directions of the geomagnetic field at the two different eruption times were opposite each other.

3 Thermo-magnetic analysis

On 193 specimens [1] from the total region of Kawajiri-misaki, the present author has conducted some laboratory experiments. Carrying out thermo-magnetic analyses, he has obtained the temperature dependency of the intensity of saturation magnetization (J_s-T curve) for 36 specimens by random selection from among the above 193 specimens. The measurements have been done by the method of sample-sealing. [3] Some typical examples of the J_s-T curves are shown in Fig. 5.

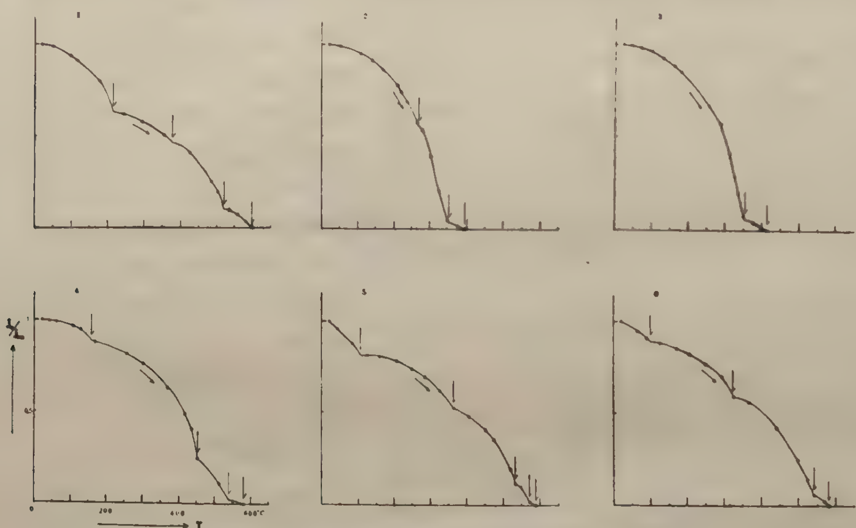

Fig. 5 Some examples of J_s-T curves.
1, 2, 3 : normal specimen
4, 5, 6 : reverse specimen

As will be seen from Fig. 5, there are several discontinuities of tangent of the curve; they suggest the Curie points of the different constituent phases of the ferro-magnetic minerals in the specimen. In other words, it is noticed that the magnetic minerals of Kawajiri-misaki lavas are, generally speaking, not composed of a single phase but of several phases different in Curie points.

Observing various Curie points from each J_s-T curve for these 36 specimens, H. Domen [4] has obtained the Curie point v.s. frequency relations for the normal and the reverse specimens. The result is illustrated in Fig. 6 in which he notices a definite difference between the normal and the reverse specimens.

Fig. 6 leads the present author to recognize that the frequency of Curie point for the normally magnetized specimens shows three peaks, of which the middle one occurring at the intermediate temperature about 370°C has a distinct maximum frequency and the remaining two peaks occurring at temperatures lower and higher than the intermediate are not sharp; and on the contrary the frequency for the reversely magnetized specimens shows two distinct peaks occurring at a low temperature about 120°C and a high one about 560°C, which temperatures may be essentially identified with those of the above-mentioned, remaining, two peaks of the normal specimens, and

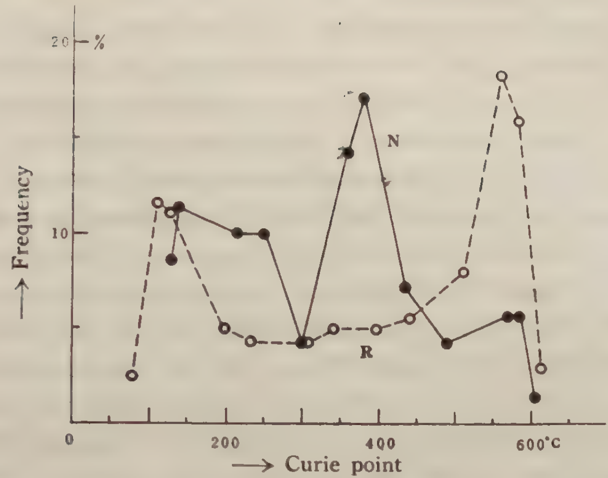

Fig. 6 Curie point v.s. frequency relation.
N : normal specimen
R : reverse specimen
(After H. Domen)

it is worth noting that at the intermediate temperature, where does occur the maximum frequency of the normal specimens, a flat minimum frequency of the reverse specimens is found. Briefly speaking, the Curie points for the normal specimens are found predominantly at intermediate temperature, whereas those for the reverse are predominant both at lower and higher temperatures than the intermediate.

4 Palaeomagnetic consideration

Next, the present author would like to put a palaeomagnetic consideration on the facts found at Kawajiri-misaki lavas.

Undoubtedly, the facts of the positional intermixing within a small area of the normal and the reverse magnetizations mentioned in section 2 do not seem to favour the geomagnetic field reversal hypothesis [5] postulated by T. Nagata and others with whom the present author joined that the reverse N.R.M. of the lavas would have been caused by a reverse geomagnetic field assumed to have occurred at the time of extrusion of the lavas. It is very likely that the positional intermixing of the normal and the reverse N.R.M. of the lavas would have been caused by the self-reversal mechanism of remanent magnetism, in other words, the whole basalt lavas at Kawajiri-misaki were extruded from the same origin and by the same eruption in the early Pleistocene age, by cooling they acquired originally a definite direction of magnetization which might be normal or reverse and the self-reversal of remanent magnetism would have afterwards occurred by a certain physical mechanism within the lavas to produce the positional intermixing of the normal and the reverse magnetizations.

The following three facts of the N.R.M. of 193 specimens already reported in the previous paper [1] seem to support the self-reversal idea of remanent magnetism. The first is the above-mentioned fact of the positional intermixing of the normal and the reverse magnetizations. The second is the fact that the intensities of magnetization are not uniform, ranging from 10^{-2} to 10^{-4} c.g.s.e.m.u./g. These can be easily explained as the results of magnetization corresponding to various stages of the self-reversal process up to the present time. The third is the fact that the directions of magnetization are not random but are, roughly speaking, either parallel or anti-parallel to the present geomagnetic field, with no intermediate directions. Moreover, both in the normal and the reverse specimens the directions of magnetization converge fairly well when their intensities of magnetization are very great being in the order of magnitude of 10^{-2} e.g.s.e.m.u./g., while they diverge far wider when very low being

10^{-4} c.g.s.e.m.u./g. Of 5 normal specimens belonging to the converging group, the standard deviations of the directions from their average value are 8.2° in declination and 3.3° in dip. Of 10 normal specimens belonging to the diverging group, the standard deviations are 17.6° in declination and 19.9° in dip. Besides, in addition to the above 193 specimens there are found more than 10 specimens having very weak magnetizations less than 10^{-4} c.g.s.e.m.u./g. and in their directions intermediate ones are found besides the normal and the reverse. This fact may suggest that at certain points of the lavas the intensity of magnetization might have turned into nearly zero as a result of self-reversal. The divergence in the directions of the N.R.M. whose intensities are in the order of magnitude of 10^{-4} c.g.s.e.m.u./g. and the existence of the intermediate directions occurring to the N.R.M. less than 10^{-4} c.g.s.e.m.u./g. are the natural consequence of the self-reversal phenomenon, as the direction of the field the parent ferromagnetic particle is producing is not always exactly anti-parallel to the direction of magnetization of the parent.

However, it is yet difficult to conclude from these field evidences whether the original magnetization of the lavas was normal or reverse. But, from the results of the thermo-magnetic experiments stated in section **3**, a key of the solution can be given as shown below.

It was already reported [5] that the main ferromagnetic mineral in all the Kawajiri-misaki rocks is titanomagnetite and of both the normal and the reverse specimens the N.R.M. is mainly due to the thermo-remanent magnetism (T.R.M.). N. Kawai and others [6] have recently proposed the idea that the self-reversal of remanent magnetism of rocks is possible to occur by means of exsolution in ferromagnetic minerals of titanomagnetite series which has occurred after the original acquisition of T.R.M. took place. From the results of their experimental research on some eruptive rocks (other than the Kawajiri-misaki basalt) which possess reverse N.R.M. and whose ferromagnetic minerals are composed mainly of the solid solution between Fe_3O_4 and $TiO_2Fe_2O_2$, they explain the process of self-reversal. The essential part of their explanation needed to the present author is as follows: At the time of formation of the rocks, the direction of magnetization was coincident with that of the geomagnetic field at this time and the magnetic mineral responsible to the magnetization was a homogeneous titanomagnetite with a certain Curie point. Then through a long period in geological time scale since the formation of the rocks, a fractional part of the parent titanomagnetite (single phase) broke up successively into two phases, one having higher Curie point and the other lower than that of the parent single-phase, and at least more than two kinds of precipitates produced by the exsolution were magnetized in the direction of the field produced by the pre-existing, parent titanomagnetite; and this direction may be assumed to be generally opposite to the direction of magnetization of the parent. Consequently, the remanent magnetism of the rocks we recognize at present is regarded as the resultant of the original magnetization of the remaining, parent phase and the opposite one of the precipitates. Hence, when the magnetization of the parent overcomes that of the precipitates, the direction of the

N.R.M. coincides with that of the geomagnetic field at the time of formation of the rocks. However, when the magnetization of the precipitates overcomes that of the parent, the direction of the N.R.M. is to be found opposite to that of the geomagnetic field at the time of formation of the rocks.

The results of the thermo-magnetic analyses of Kawajiri-misaki lava specimens seem to be consistent with this self-reversal idea of remanent magnetism. Besides, it has also been ascertained that the Kawajiri-misaki lava specimens indicate the same characteristics as demonstrated by N. Kawai's experiments [6] that the sudden inversions of the direction of magnetization of the specimen take place when it is continuously heated. The results mentioned in section **3** suggest that the magnetic mineral responsible to the normal N.R.M. of the Kawajiri-misaki lavas is predominantly a titanomagnetite of a phase having intermediate Curie point, whereas those to the reverse N.R.M. poly-phase having lower and higher Curie points than the intermediate. Thus, from the author's results of these thermo-magnetic experiments and N. Kawai's idea of self-reversal phenomenon due to exsolution, the following interpretation is possible for the observed facts of the N.R.M. of the Kawajiri-misaki lavas.

In the early Pleistocene age, about a million years ago, when the Kawajiri-misaki lava was extruded, the geomagnetic field was normal. In the course of cooling of the lava, the single-phased titanomagnetite acquired T.R.M. after it had cooled below its Curie point about 370°C in the direction of this geomagnetic field. This is the original magnetization of the lava and the direction of magnetization is normal. Since this magnetization, the single-phased titanomagnetite underwent exsolution giving rise to children of different titanomagnetites having Curie points lower and higher than that of the parent. By the field of the parent titanomagnetite, magnetization would have occurred on some children titanomagnetites having the lower Curie points, provided that they are lower than the temperature to which these children titanomagnetites were exposed when magnetized; and the direction of magnetization of these children was generally opposite to the direction of magnetization of the parent. Until the present time, new children titanomagnetites came into existence one after another and similar opposite magnetization occurred, resulting in increasing the total intensity of the opposite magnetization and at the same time in decreasing that of the original magnetization within a small volume of the lava. As mineralogical composition of the lava at the time of its solidification would have been different from point to point, the relative magnitudes of the present opposite magnetization and original one should be different from point to point of the outcrop of the Kawajiri-misaki lava. Consequently, the N.R.M. of a volume of hand specimen size in which the present total intensity of the original magnetization overcomes that of the opposite one is to be found normal, while that in which the present total intensity of the opposite magnetization overcomes that of the original is to be found reverse. The fact of the positional close intermixing of the normal and the reverse N.R.M. whose intensities are as weak as 10^{-4} c. g. s. e. m. u./g. in order of magnitude within entirely one rock block shown in section **2** can be reasonably explained as the results of magnetization corres-

ponding to the condition that at any points in the rock block two intensities of the present original magnetization and opposite one amount to fairly comparable magnitudes and one slightly overcomes the other according to the sampling position.

If we assume that the direction of the geomagnetic field at Kawajiri-misaki in the early Pleistocene age was opposite to that of the present geomagnetic field, the maximum frequency of the intermediate Curie point (the parent titanomagnetite) should be found not for the normal specimens but for the reverse. But our observed fact of the Curie point v.s. frequency relation is reverse to this, suggesting that the reverse N.R.M. of the Kawajiri-misaki lavas hardly favour the geomagnetic field reversal hypothesis.

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LETTER TO THE EDITOR

Relations among Radio Absorbing Regions, Geomagnetic Bay-Disturbances and Slant-E_s in Auroral Latitudes

Relations between ionospheric and geomagnetic phenomena in auroral latitudes were investigated, using both ionograms obtained every 15 minutes with vertical incidence ionosondes (N.B.S., Model C-3) and magnetograms, made at College (64.9°N, 147.8°W; gm lat. 64.5°N) and Point Barrow (71.3°N, 156.8°W; gm lat. 68°N), Alaska, during the period of one year starting from March 1955. Ionograms made in auroral latitudes often show the arctic no-echo phenomenon named the "polar blackout." This phenomenon has been studied by many workers. Appleton, Naismith and Ingram [1] found that the phenomenon occurred at Tromsö during magnetic disturbances, and Wells [2] reported briefly that polar blackouts occurred during magnetic bays using data from College for 1942. However, the polar blackouts also occur even on magnetically quiet days. In connection with the study of ionospheric storminess, Meek [3] examined the diurnal and seasonal variation of the occurrence of blackouts. Piggott [4] and Agy [5] obtained geographic and temporal distributions of polar blackouts. These reported results are not always consistent in showing correlation between ionospheric blackouts and geomagnetic phenomena. In this communication, the author describes correlations among blackouts, complete blanketing of $F2$, geomagnetic bay and Slant-E_s. The result follows that there are two types of polar blackouts. A cause of the formation of radio absorbing regions in auroral latitudes is then described to explain these statistical results.

For purposes of analysis, the data were classified into quiet ($A_p<16$) and disturbed days ($A_p\geq16$) during three seasons—summer months (from May to August), equinoctial months (March, April, Sept. and Oct.) and winter months (from Nov. to Feb.). Ionograms made during periods in which there were troubles of the ionosonde were carefully eliminated to distinguish real blackouts.

In auroral latitudes, large magnetic bay-disturbances often occur at night, most frequently at about 02 or 03 h. local time, even on small A_p-index days, particularly in equinoctial months. The positive-bay occurs before 22 or 23 h. local time, and the negative-bay occurs after that time. The negative-bay seems to be closely related to a sequence of change in the type of auroral activity [6]. When the range of horizontal component of the bay is moderate at College (100–200γ ($A_p<16$) and 200–300γ ($A_p\geq16$) for positive-bays, and about 200γ ($A_p<16$) and 300–400γ ($A_p\geq16$) for negative-bays), complete blanketing of $F2$ by abnormal-E always occurs, corresponding to the time at which the bay takes place. When the range of the bay is larger than above

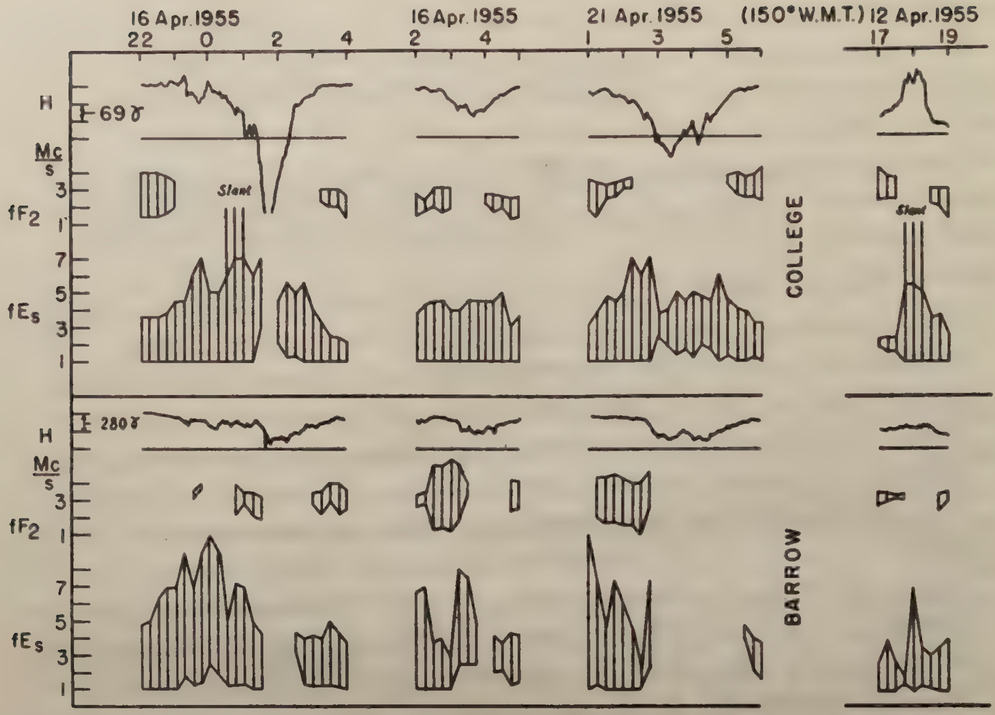

Fig. 1. Examples of the occurrence of complete blanketing of $F2$, gradual blackouts, and Slant-E_s, associated with magnetic-bays, at College and Point Barrow, Alaska. Variations of f_oF2, *f-min-F*, fE_s and *f-min*, every 15 minutes, and geomagnetic horizontal variations are compared in this figure.

values, the blackout usually occurs after the incidence of complete blanketing of $F2$. This is called "gradual blackout". Figure 1 shows examples of these relations. When the range of bay is smaller than about 100γ, no remarkable variation occurs in ionograms. In the present study, the multiple type of E_s which blankets the upper ionosphere was ignored, in fact it did not frequently occur. This type of E_s had no correlation with magnetic variations.

As will be seen in the Figure 1, a type of sporadic E, called "Slant-E_s," occasionally appears during bays, particularly during positive-bays, and it never occurs except during bays or bay-type variations during magnetic storms. The time of most frequent occurrence of Slant-E_s is 18–20 h. local time on disturbed days. From the modes of radio propagation for Slant-E_s, which have been suggested by Smith [7], the occurrence of Slant-E_s indicates the formation of an ionized region which scatters radio waves under the E level. In other words, an ionized region is occasionally formed under the E level during magnetic bays. Heppner, Byrne and Belon [8] reported that Slant-E_s was associated with aurorae. Accordingly the ionized region under the E is supposed to relate to incidence of auroral particles.

These results on the occurrence of gradual blackouts, complete blanketing of $F2$, and Slant-E_s, associated with bays, imply an increase of ionization and hence of these nighttime absorption of radio waves in the level of 80–100 km which are responsible

for the electric current producing the geomagnetic variation.

During the daytime, 08–20 h. in auroral latitudes, blackouts often occur suddenly both on quiet and disturbed days without any relating magnetic variations. This is named "sudden blackout" in the present study, and has maximum occurrence frequency at 11–14 h. on disturbed days. This sudden blackout means that the height of the absorbing region during daylight hours is lower than that at night; in other words, lower than the level responsible for the geomagnetic variation. Accordingly we may conclude that there are two different blackouts—gradual blackout which occurs only at night and sudden blackout in the daytime—and that the radio absorbing regions responsible for the two are situated at different heights.

According to the magneto-ionic theory of radio wave propagation, the absorption coefficient K of a wave of angular frequency ω, per unit path length, in a medium containing N electrons per unit volume, is given by

$$K=\frac{2\pi e^2}{\mu mc}\cdot\frac{N\nu}{\nu^2+(\omega\pm\omega_L)^2},$$

where μ is the refractive index,

c is the velocity of electromagnetic waves in vacuum,

e and m are the charge and mass of the electron,

ν is the effective electron collision frequency,

ω_L is the angular gyro-frequency corresponding to the longitudinal component of the earth's magnetic field.

The positive sign in the denominator refers to the ordinary wave and the negative sign to the extraordinary wave.

For nondeviative absorption of the ordinary component of radio waves, the absorption along the path through a stratum of S [9] is expressed in decibels as follows:

$$\int K\,ds \simeq \frac{A}{(f+f_L)^2}\int N\nu\,ds,$$

where $A=1.17\times10^{-14}$, and f and f_L are the radio and gyromagnetic frequencies expressed in Mc/s;

$$f_L=10^{-6}eH\cos\theta/2\pi mc=2.80\,H\cos\theta \quad \text{(e.s.u.)},$$

in which θ is the angle between the direction of wave propagation and the magnetic field, and H denotes the geomagnetic field (gauss).

At College, $H\cos\theta$ for vertical incidence is 0.55 gauss, and f_L is 1.54. For the phenomenon of polar blackouts, 15 Mc/s may be sufficient for the value of f. Accordingly,

$$\int K\,ds=4.27\times10^{-17}\int N\nu\,ds.$$

To find the order of the value N, we assume that the thickness of the layer responsible for the polar blackout is 10 km. The order of the values ν in different heights is assumed as follows:

Height in km	50	70	85	100
ν	10^8	10^7	10^6	10^5.

Then the order of magnitude of N for different values of the absorption is

Absorption (db) \ Height (km)		50	70	85	100
5	$1.17\times$	10^3	10^4	10^5	10^6
10	$2.34\times$	10^3	10^4	10^5	10^6.

To explain the already mentioned statistical results, we must have 10^3–10^4 electrons per unit volume in the day time and 10^5–10^6 at night, from this speculative estimation. Usual solar charged particles seem to be difficult to reach and ionize to this extent at levels lower than 90 km. Van Allen [10] observed by a rockoon that X-rays penetrated to the level as low as 50 km in auroral latitudes. He estimates that production of electron-ion pairs by these X-rays is $10^8/cm^2$ sec. in a 10 km thickness. To explain the absorption in auroral latitudes, these X-rays generated by the primary bombarding particles from the sun, as also suggested by Chapman and Little [11], may be an important factor. These X-rays penetrate further than the particles and may ionize there to the extent of the above obtained order of N. Lyman-alpha radiation generated by the auroral protons, as pointed out by Bates [12], may also contribute to the absorbing region.

The electrons become increasingly attached to form negative ions below about 100 km. However, the ratio of electrons to negative ions in the daytime may be larger, by photodetachment, than that at night. Accordingly, the same X-ray produces a weaker absorbing region by night than by day, at lower levels than the E. This effect may be sufficient to outweigh that of a greater flux of primary particles at night, as Chapman [11] has suggested. The difference between sudden blackouts in the daytime and gradual blackouts at night may be explained by this effect.

The average electric current-system of bay was obtained by Hatakeyama [13]. In the auroral zone and polar cap however, this system in the dark hemisphere is distorted by a lag of about three hours, because the boundary of occurrence of positive- and negative-bay is 22–23 h. Each bay-disturbance seems to occur in a patchy structure due to patchy bombardment by primary particles. The increase of electron number density due to primary particles and X-rays causes an increase of electrical conductivity in the region responsible for the magnetic variation (mainly nighttime); hence, bay-current is explained by the dynamo theory in the same way as the calculation for the S_D variation [14]. For the recurrence tendency of occurrence of bay during 2–4 days even on quiet days and for the patchy structure, we may suggest the effect of deflection of the path of solar particles due to the magnetic field of magnetized gas clouds which may be situated in the outer atmosphere [15].

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